

**DEVELOPMENT OF SYNCHRONVERTER CONTROL FOR INDUCTION
MOTOR CONNECTION**

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My beloved and lovely parent, my beloved brothers and sisters, and all my friends



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ABSTRACT

More and more attention has been paid to the energy crisis due to the increasing energy demand from industrial and commercial applications. The utilization of renewable energy considered as one of the most promising electrical energy sources, which has grown rapidly in the last three decades. In this day and age, many power converter techniques have been developed to integrate renewable energy with the electrical grid. In this work, there is a new technical control is known as synchronverter control which is using the synchronous generator mathematical equations as a reference. This synchronverter control is connected with DC-AC three phase inverter to work as controller of output power to feed the load. In this control strategy, the output current of the controllable inverter is controlled by a feedback load current according to the current reference. The synchronverter technology has been applied to control the inverter for the induction motor connection. An experimental setup based on DSP (Digital Signal Processing) and dc drive board have been designed to implement the open and closed loop experiments. All experiments have been implemented on a test rig based on Matlab 20013a/simulink software and Code Composer Studio V6.0 to demonstrate the excellent performance of the proposed control strategies with stability of the system, sinusoidal currents and good dynamics. Finally, an improve control strategy based on the synchronverter control technology has been tested for three phase inverter for renewable energy applications to make the whole system behave as a synchronous generator.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	-	Alternative current
A	-	Area swap
ADC	-	Analag digital converter
BJT	-	Bipolar junction transistor
C	-	Capacitor
Dp	-	Damp coefficient
DSP	-	Digital signal processing
DC	-	Direct current
EMF	-	Electrical magnetic field
F_0	-	Frequency
f_c	-	Cut off filter
F	-	Farad
hrs	-	Hours
IGBT	-	Insulated gate bipolar transistor
IM	-	Induction motor
i_f	-	Current field
L	-	Self-inductance
L	-	inductor
M	-	Mutual inductance
mf	-	Mutual field
MPPT	-	Maximum power point taking

MOSFET	-	Metal-on-semiconductor field-effect
PID	-	Proportional integral derivative
PWM	-	Pulse width modulation
PMSM	-	Permanent magnet synchronous motor
P	-	Power generated
Q	-	Reactive power
R	-	Resistor
V	-	Voltage
VSC	-	Voltage source converter
VSI	-	Voltage source inverter
VC	-	Vector control
ν	-	Rotor speed
VISMA	-	Virtual synchronous machine
W	-	Watt
λ	-	Speed ratio
Ω	-	Ohm
μH	-	Micro farad
θ	-	Virtual angle
$\dot{\theta}$	-	Virtual angle speed

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CHAPTER 1

1.1 Introduction

There has been a sharp increase in the use of voltage source dc/ac converters connected to the power networks for renewable energy systems such as wind turbines, hydraulic generators, biomass and geothermal generators, photovoltaic systems, fuel cells, storage devices, and power quality improvement units (flexible AC transmission systems (FACTS), active power filter (APF), voltage source converter (VSC) transmission) [1-3].

DC-AC converters is known as inverter. An inverter is an electrical device that converts direct current (DC) to alternating current (AC), and this alternated power can be maintained in any frequency or voltage with the use of appropriate transformers, circuits and switches to supply the grid or load with power.

Inverters are the devices used to interface renewable energy sources to the utility grid, most of renewable energy sources are connected to the utility grid through a three-phase voltage source inverter (VSI). For efficient connection, the three-phase voltage source inverter is controlled through a grid-side controller dedicated to meeting the power demands of the grid and controlling the quality of the injected current [1, 4].

Although the basic circuit for an inverter may seem simple, accurately switching these devices provides a number of challenges for the power electronic engineer. The most common switching technique is called Pulse Width Modulation (PWM). PWM is a powerful technique for controlling analog circuits with a

processor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. The PWM inverters make it possible to control both frequency and magnitude of the voltage and current applied to system.

This three-phase inverter system for renewable energy sources are operated as stand-alone- or grid-connected mode. For the stand-alone mode operation, it keeps the voltage and frequency constant, but it is difficult to regulate the voltage and frequency constantly due to the continuous change of load. Therefore, it has been strongly recommended to design the inverter controller with fast and stable response. Renewable energy sources their control system is traditionally based on current vector control (VC) and pulse width modulation (PWM). The vector control decouples the converter current into active and reactive power components, which are then regulated separately by current controllers. The performance of such a vector-controlled dc/ac converter largely depends on the accuracy of the current decoupling, the design of the current controllers, and the tuning of their parameters. Recently, current control based on predictive methods has been proposed, which provides direct regulation of the current using the converter voltage [5-7].

The control techniques that are commonly used in grid connected converter systems could be classified as direct or indirect control strategies. The indirect control is characterized by a modulator (pulse width modulation (PWM) that computes the turn-on/turn-off times of a converter's switches along a switching period through the evaluation of the voltage reference. This voltage reference is issued by the controller, which idealizes the converter as a dependent continuous voltage source. On the other hand, direct control techniques establish a direct relation between the behaviour of the controlled variable and the state of the converter's switches [8].

Generally, the inverter controller has a double loop controller with an outer voltage controller and an inner current controller. Those are designed basically by using synchronverter controller, and it can be implemented using the virtual angular speed comparing with the angular frequency reference.

However, the more controllers are added the higher the system order and it makes the controller design difficult and complex. Additionally, a high order system is very weak to the noise, therefore, it is necessary to choose a controller to be low order as well as fast time response.

Nevertheless, indirect control strategies generally lead to good transient behavior and acceptable steady-state operation; they operate at a constant-switching frequency, which makes the use of advanced modulation techniques possible. Thus, it becomes easier to optimize conversion power losses or simplify the line side filter design.

1.2 Problem Statement

The demand for electricity for commercial, industrial and domestic loads in rural, semi-urban and urban areas has grown tremendously over the years. The increase of energy consumption increases the demand on renewable energy, and more grid-connected systems are used. However, it is an important to design three phase dc/ac grid inverter to back up this grid with power.

The main point in this project is to design a three phase inverter which operates as a current source to feed the induction motor load with current. This is required to develop a synchronverter feedback current controller to dominate of this load current. However, it is a significant major to design a control system to integrate into the existing system and behave in the same way as synchronous generators.

All expected obstacles should overcome by depth in searching and by using different control system ways to develop simulation model of controlled three phase grid inverter, also implement three phase hardware inverter circuit with DSP board to obtain output current to supply induction motor connected load.

1.3 Project objectives

The significant objectives of this project are:

- i. To design the three phase inverter and inverter circuit driver model.
- ii. To interface the MATLAB Simulink and the TMS320F28335 microcontroller to generate PWM signal.
- iii. To control the current that supply from three phase inverter into the load.
- iv. To improve the existing synchroconverter model controller by using MATLAB Simulink.

1.4 Scope of project

This project is primarily concerned with development of synchronverter control for three phase inverter. The scope of this project is divided into two parts which can be hardware and software Simulink as follows:

- i. The synchronverter control using synchronous generator equation will be designed in the MATLAB.
- ii. The connection between the inverter and the load must be established using MATLAB Simulink.
- iii. Design and build an electric circuit for three phase DC/AC inverter induction motor connection.
- iv. Understanding the concept of synchronverter controller that uses for close loop control.

CHAPTER 2

2.1 Switching Technologies

Historically, inverters have been made with every kind of switching apparatus such as rotating or vibrating mechanical contacts, gas-filled electronic valves and thyristors (SCRs). However, in contemporary use the field is led by two special kinds of transistor.

The first kind is the Metal-On-Semiconductor Field-Effect Transistor (MOSFET); this device has a very rapid switching action and can be designed with a low resistance so that it will pass high currents efficiently. MOSFETs designed to withstand high voltages have a much higher 'ON' state resistance making them less efficient, whatever the voltage rating, MOSFETs are electrically robust and difficult to destroy by excessive voltage or current.

Complementing the MOSFET is the Insulated Gate Bipolar Transistor (IGBT) when designed for high 'OFF' state voltages, this outperforms MOSFETs although the MOSFET is still best at lower voltages, IGBTs switch rather slower than MOSFETs and are not quite as resistant to damage by overloads.

Given these advantages and disadvantages, the actual device chosen will depend on what sort of inverter circuit is chosen. This determines the voltages and currents imposed on the devices and on what control algorithm is chosen. This determines the speed at which switching must be performed [9].

2.2 Type of Inverter

Inverter can divide into two are which current source inverter and voltage source inverter. Voltage source inverter produces square wave output and the output depends on source as is illustrated in Figure 2.1, output frequency depends on frequency output voltage square wave. Advantage of this inverter is the circuit is simple and capable whereas disadvantage is high harmonic factor.

For current source inverter the output can control by using PWM technique, this inverter capable to reduce harmonic factor and not needed filter but the circuit is complex and expensive, the circuit diagram of the current source inverter is illustrated as in Figure 2.2.

A power MOSFET is a voltage controlled device and requires only a small input current, the switching speed is very high and the switching times are in the order of nanoseconds. Power MOSFET finds increasing applications in the low-power frequency converters. MOSFET does not have the problem of second breakdown phenomenon as do Bipolar Junction Transistor (BJTs). Second breakdown phenomenon is a destructive phenomenon, results from the current now to a small portion of the base, producing localized hot spots other than that Power MOSFET are low switching loss and simple gate drive circuit [10].

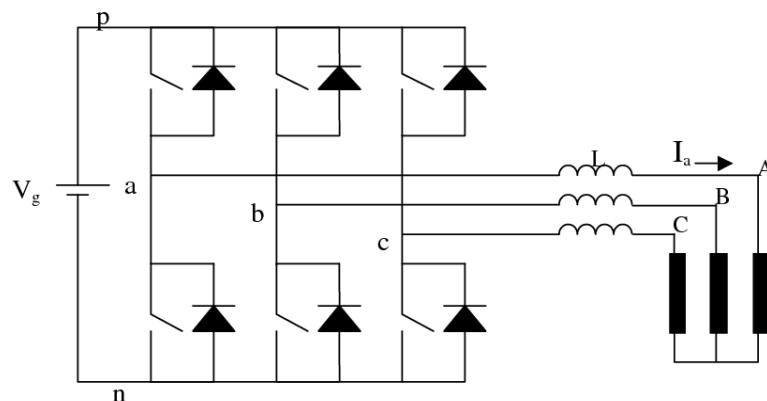


Figure 2.1: Circuit diagram of voltage source inverter.

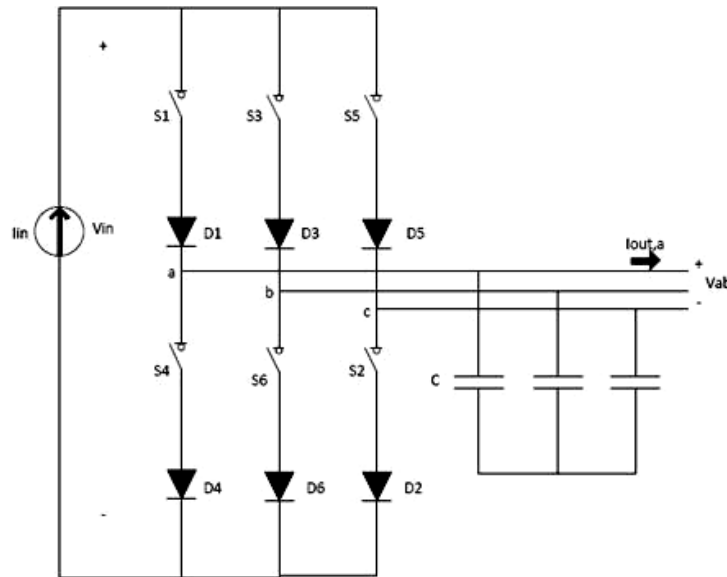


Figure 2.2: Circuit diagram of Current Source Inverter.

2.3 History of Control System

Control systems are older than humanity, numerous biological control systems were built into the earliest inhabitants of the planet. Knowledge of the control system of the Hellenic period was preserved within the Islamic culture that was rediscovered in the west toward the end of the renaissance, new invention and application of hold principles began to appear during 18th century [11].

Speed control has been introduced since 17th century, James Watt (1736-1819) was invented the fly ball speed governor to control the speed of rotary engine governor, he was provided proportional speed control and hence exact control of speed at only one operating condition, it also can operate only over a small speed range. In 1745 Edmund Lee was control the speed of windmill; he was increasing wind pitched blades further back, so that less area was available. As the wind increased, more blades were available; William Siemens (1823-1883) substituted integral action for proportional action and hence produced controllers with no fix point. The early years of the 20th century saw the rapid and widespread application of feedback control for voltage, current and frequency regulation such as motor speed and position control, temperature, pressure and flow in process industry.

Elmer Sperry (1911) developed the automatic ship steering mechanism that incorporated PID controller and gain adjustment to compensate for the disturbances caused when the sea condition changed. In 1922 Nicholas Minorsky presents a clear analysis of the control involve in position control system and formulated a control law that we now refer to as three-term or PID controller [12].

2.4 Wind Turbine

Energy shortage and environment pollution are the important problems for the human lives and social development. Traditional mineral energy such as coal, oil and gas will be used out in a few years and will cause serious environmental problems. So the renewable energy, especially wind energy and solar energy have become more and more considerable all over the world. In the wind energy conversion system, the wind turbine captures the wind energy. Then the generator converts it to the electrical power. So the characteristic of the wind turbine is very important. Because the wind turbine is big and expensive, it is not convenient to do the research in the practical wind farm. To develop a wind turbine simulator which can simulate the real wind turbine in the steady state and dynamic state is very meaningful for laboratory research. It can improve research effectiveness and efficiency [13].

A few research works about wind turbine simulator have been done in the past few years, presented a wind turbine simulator based on a DC machine. The armature and the field current were controlled so that the DC machine can generate the static characteristics of a wind turbine [14], presented a wind turbine based on SCR-DC motor controlled by a microcomputer. But the DC machine is big, expensive and it need to frequent maintenance because of brushes compared with an AC machine. Presented an IGBT inverter-controlled squirrel cage induction motor (IM) instead of a dc motor. Wind turbine simulator based on the permanent magnet synchronous motor (PMSM) has some advantages such as high power density, small size, high precision and easy to control.

The typical structure of variable-speed wind energy conversion system is shown in Figure 2.3. The system comprises wind turbine, generator, rectifier,

inverter and LC filter. In this system, the wind turbine captures the wind energy and the generator converts it to the electrical power. Then the power electronics equipment converts it to the high quality power and controls the rotor speed of the generator, the inputs and output variables of wind turbine can be broken into the following:

1. The independent input quantity wind speed, determines the energy input to the wind turbine.
2. Machine-specific input quantities, arising particularly from rotor geometry and arrangement (i.e., different configurations like horizontal axis or vertical axis turbines, area of the blades, etc.).
3. Turbine speed, rotor blade tilt, and rotor blade pitch angle, arising from the transmission system of the wind energy conversion system.
4. Turbine output quantities, namely Power or Drive torque, which may be controlled by varying the above three input quantities, the aerodynamic model of wind turbine is given by [15]:

$$P = \frac{1}{2} \rho A C_p(\lambda) v^3 \quad (2.1)$$

Where P is the power generated by the wind turbine, ρ is air density, A is the area swept and λ is tip speed ratio, where v is wind turbine rotor speed in revolutions per minute(r/min).

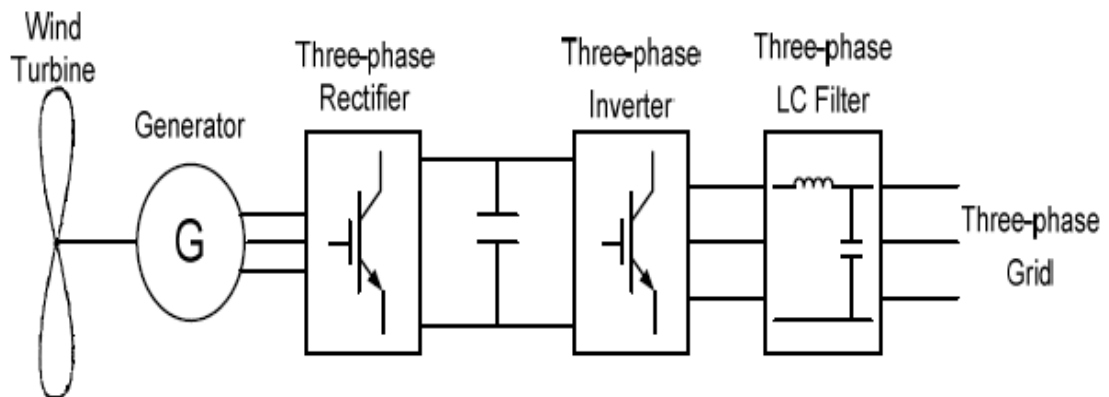


Figure 2.3: The structure of variable-speed wind energy conversion system.

Renewable energy plays an important role in the supply of energy, when renewable energy sources are used; the demand for fossil fuels is reduced. Unlike fossil fuels, non-biomass renewable sources of energy “hydropower, geothermal, wind, and solar” do not directly emit greenhouse gases.

2.5 Solar Energy

In tropical countries, solar energy potential in wide range of applications of remote and urban areas is growing rapidly. There are also new research interests shown by the universities and R&D institutions to assess the solar energy application potential in these countries for proper utilization.

Since solar energy depends on solar presence in a particular zone, correct and accurate information from the sun, seasonal changes of the solar energy and the amount of solar energy received from the sun are necessary to be evaluated and the basic parameters of solar energy system are needed to be as accurate as possible. This paper presents forming practical and standard guidelines for feasibility studies, solar development studies, solar engineering studies and selecting solar energy equipment while implementing any viable solar energy scheme. It describes the best steps necessary to take into account for implementing practical solar scheme successfully. It discusses complete analysis of practical evaluations of all factors, which involve practical solar energy scheme in terms of assessment, application design, effective energy production [16, 17].

The output of a solar panel is commonly expressed in watts, and the wattage is determined by multiplying the rated voltage by the rated current for example, a 12 V, 60 W solar panel measuring in inches of "20 x 44" has a rated voltage of 17.1 V a rated current of 3.5A which is, $V \text{ (volts)} \times A \text{ (amps)} = W \text{ (watts)}$, $17.1 \text{ V} \times 3.5 \text{ A} = 60 \text{ W}$.

If an average of 6 hours of peak sun per day is available in an area, then the above solar panel can produce an average of 360 watt-hour of power per day; $60 \text{ W} \times 6 \text{ hrs} = 360 \text{ W.hrs}$. Since the intensity of sunlight contacting the solar panel varies throughout the day, the term "peak sun hours" is used as a method to smooth out the

variations into a daily average. Early morning and late-in-the day sunlight produces less power than the mid-day sun [16, 17, 18].

Naturally, cloudy days will produce less power than bright sunny days as well. When planning a solar power system the geographical area is rated in average peak sun hours per day based on yearly sun data. Although Average peak sun hours for various geographical areas are known but it is very important to exactly utilize the daily peak sun hour's in a particular zone in a particular period [18]. This will do away any daily planning which could be based on assumption of the former data while ignoring the exact data available in the particular day at the particular zone.

Solar panels can be wired in series or in parallel to increase voltage or current respectively, and they can be wired both in series and in parallel to increase both volts and amps. Series wiring refers to connecting the positive terminal of one panel to the negative terminal of another.

The resulting outer positive and negative terminals will produce voltage the sum of the two panels, but the current stays the same as one panel. So two 12V/3.5 amp panels wired in series produces 24 V at 3.5 A. Four of these wired in series would produce 48V at 3.5 A. Parallel wiring refers to connecting positive terminals to positive terminals. And negative to negative. The result is that voltage stays the same, but current becomes the sum or the number of panels, so two, 12V/3.5A panels wired in parallel would produce 12 V at 7 A. Four panels' would produce 12 V at 14 A. Series- parallel wiring refers to doing both of the above; increasing volts and amps to achieve the desired system voltage as in 24 or 48 V systems. In addition to that, the four panels can then be wired in parallel to another four and so on to make a larger array.

As a rule-of-thumb each so-called peak-Watt (Wp) of solar panel power can deliver around 4 -5 watt-hours of energy per day in tropical countries like Malaysia. Therefore a 40Watt solar panel would supply about $40 \times 4 = 160$ Watt- hours per day. As a further example, an array of $10 \times 50\text{W} = 500$ solar panels can provide $500 \times 4 = 2000$ Watt-hours per day.

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